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THE CHEMICAL CONTROL OF POSTHARVEST DISEASES: SUBTROPICAL AND TROPICAL FRUITS[1]

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INTRODUCTION

International organizations responsible for monitoring food resources have recognized that the most economically feasible and expedient means to increase the world food supply is to reduce losses in food crops that occur after they are harvested (48, 117). Because of their high moisture content, fresh fruits, vegetables, and root crops are very susceptible to attack by pathogenic fungi and bacteria during the period between harvest and consumption. Postharvest losses of perishable crops in developing countries have been authoritatively estimated to be in the range of 5–50% or more of the harvest (48, 145, 167). Even in production areas with the most advanced technologies available, postharvest food losses are still substantial (37, 61, 107, 125, 138, 179).

Although postharvest food losses and diminished nutritional value are rightfully a major concern, other consequences of microbial deterioration are often overlooked: (*a*) partial or total loss of consumer packages due to one or several diseased units; (*b*) reduced storage life of perishable crops due to accelerated ripening or senescence triggered by ethylene from a few diseased fruits in the environment (153, 207); (*c*) contamination of foodstuffs by mycotoxins elabo-

[1]The control of postharvest diseases of temperate-zone fruits, vegetables, root crops, and tuber crops will be covered in a subsequent issue of the Annual Review of Phytopathology.

rated by plant pathogens (118, 166, 193, 194); (*d*) toxic metabolites produced by diseased plant tissue in response to fungal attack or exposure to ethylene (35, 100, 209); (*e*) unacceptable taste of produce or products associated with diseased plant material (e.g. orange juice prepared from fruit infected with *Alternaria* and carrots exposed to ethylene from diseased fruit); and (*f*) disintegration of processed fruits by heat-tolerant pectolytic enzymes of postharvest pathogens—e.g. *Rhizopus* and *Sclerotinia* (4, 104, 196).

Postharvest diseases of fruits and vegetables can be suppressed by low-temperature storage, a low-oxygen atmosphere, and treatment with growth regulators that delay tissue senescence. However, these beneficial practices may not adequately protect the crop from microbial attack, especially during prolonged storage or movement of the crop through marketing channels. This is particularly true for crops of tropical origin such as bananas, sweet potatoes, and lemons, which are injured by the near-freezing temperatures required to inhibit pathogenic fungi for an extended period. Maximum storage life of many fruits and vegetables can be achieved only by treating them with an antifungal agent before storage in an environment that is optimum for maintenance of the desired crop qualities. An antimicrobial treatment is not a substitute for a satisfactory storage environment, since these treatments rarely influence the rate of physiological deterioration of the perishable product. The antifungal agent is most effective when the treated product has intrinsic resistance to infection and the environmental conditions are least favorable for growth of the pathogen. However, in situations where controlled environmental storage is either unavailable or not affordable, an antimicrobial treatment may be the only means of extending the postharvest life of a perishable crop (19, 88). Indeed, the widely accepted notion that refrigerated storage is the ultimate solution to postharvest deterioration of harvested tropical crops has been questioned on the grounds that this practice is an inefficient utilization of energy resources in developing countries (179).

In this review we focus on the postharvest application of chemical treatments to control microbial deterioration of subtropical and tropical fruits during storage and marketing. We emphasize advances in the field since 1967, the date of the last *Annual Review* article on the subject (73). Postharvest diseases of temperate-zone fruits, vegetables, and root and tuber crops will be considered in a subsequent review.

STRATEGIES FOR POSTHARVEST DISEASE CONTROL

Strategies employed to control postharvest diseases include (*a*) inoculum reduction, (*b*) prevention and eradication of field infections, (*c*) inactivation of wound infections, and (*d*) suppression of disease development and spread.

Inoculum Reduction

The number of infectious propagules at a potential infection site is usually a major determinant of disease severity following either field inoculation or postharvest wound inoculation. The inoculum level determines not only the number of lesions but also the probability of latent infection of tropical fruits (161). An inoculum threshold exists (*a*) for direct infection of uninjured citrus fruits by appressoria of *Colletotrichum gloeosporioides* (23) and zoospores of *Phytophthora parasitica* (152); and (*b*) for the infection of wounds on citrus fruits by *Penicillium digitatum* (206) and *Geotrichum candidum* (12) and on pears by *Mucor pyriformis* (16). Several investigators have described inoculum thresholds for *Erwinia carotovora* in the development of bacterial soft rot on potatoes (156). The existence of an inoculum threshold implies that a reduction in amount of inoculum on the harvested crop will result in less postharvest disease.

Preharvest fungicide treatments have decreased spore production by *Gloeosporium* spp. in the branches of apple trees (32, 45) and *Botrytis* on flowers and debris in strawberry plantations (55, 114). After harvest, sanitation of the atmosphere, of water dumps, and of crop-handling equipment was shown to reduce the amount of inoculum and the severity of postharvest diseases in several instances (8, 16, 113, 131, 171, 190, 191).

Prevention and Eradication of Field Infections

Fruits, vegetables, and potatoes are often inoculated or infected during their development in the field. Due to the inherent or induced resistance of the host tissue, or to some morphological barrier, the pathogen is unable to produce an active disease lesion, but rather enters a quiescent state on or in the host (197). The pathogen persists in this condition until the resistance of the host declines with advancing maturity or until the pathogen is activated, either by a wound to the host tissue or by some other mechanism that weakens the host defenses.

In tropical and subtropical areas, latent infections of *Colletotrichum* are common on bananas, mangos, papayas, avocados, and citrus fruit at harvest time. Spores of the pathogens are carried to the immature fruit by rain-splash; the spores germinate in a few hours and form appressoria. Some of the appressoria germinate to form infection hyphae. By mechanical force aided by the enzyme cutinase (59), these penetrate the cuticle and develop to a limited extent in the epidermal layer of the fruit. Continued growth of the pathogen is prevented by the resistance of the immature host tissue. However, most of the appressoria do not germinate immediately, but remain firmly attached to the host surface where they function as the latent stage of the pathogen (197). Penetration of the cuticle of green bananas by *C. musae* resulted in the formation of necrotic lesions that contained several fungitoxic compounds (21).

The subcuticular hyphae that formed in green banana fruits did not resume growth when the fruit ripened, indicating that the latent appressoria were indeed the inoculum that gave rise to progressive anthracnose lesions on ripe fruits (141). The appressoria also appeared to function as the latent stage of *C. gloeosporioides* on avocados (17), mangos (50), and citrus (23). The current view that appressoria rather than the subcuticular hyphae (178, 192) function as the latent stage of *Colletotrichum* on some crops is significant to disease control since appressoria are more easily contacted by a surface-applied fungicide than are the subcuticular hyphae. On the other hand, appressoria are more resistant to toxic chemicals than are hyphae and spores of the same pathogen (85, 141). Recent studies on *C. gloeosporioides* on blueberries (54) and *Alternaria* on persimmons (160) showed that subcuticular infection hyphae function as the latent stage of these diseases following field infection.

Stem-end rots of citrus fruits caused by *Diplodia* and *Phomopsis* are the major postharvest diseases when these fruits are grown in humid subtropical areas. These diseases arise from quiescent infections in the stem button (calyx + disc). Infections are initiated at all stages of fruit development when rainfall is adequate for dispersal of the pycnidiospores of the pathogens. Propagules of the pathogens remain quiescent under the sepals of the fruit and do not become active until the buttons become senescent and begin to separate from the fruit. Several other pathogens may establish quiescent infections on developing fruit if sufficient rain falls late in the growing season: *Botrytis cinerea* on grapes (108), *Monilinia fructicola* on stone fruits (115), and *Phytophthora* spp. on citrus fruits (198).

Lenticel-rotting of apples, a major storage disease of fruit grown in Europe and other humid areas, arises from latent infections of *Gloeosporium* spp. which develop in the fruit lenticels during periods of relatively high temperature and rainfall late in the summer. The pathogens remain quiescent in the lenticels until the apples gradually lose resistance to infection after several months in storage (75). Lenticels of potato tubers are a common site of initiation of bacterial soft rot after harvest (156). The lenticels of most tubers are contaminated with *Erwinia carotovora* at the time of harvest, but the bacteria remain quiescent in the lenticels until the tubers are subjected to environmental conditions or injuries that increase their susceptibility to decay.

Infections that are well-established or latent at the time of harvest are difficult to eradicate by postharvest application of protective fungicides. The traditional approach to this problem has involved field applications of fungicides to the developing fruit to prevent spore germination and the formation of appressoria or deep-seated infections in the lenticels or in the floral remnants on the fruit. Protective sprays on a 7–14-day schedule have been widely used to prevent anthracnose on mangos (136, 161), papayas (2, 18), avocados (52, 140, 157), and bananas (90, 91). Fungicides applied to strawberries and raspberries in the field on a 7–14-day interval during the period of flowering and fruit development have controlled *Botrytis* rot after harvest (55, 114). Chlorothalonil, dichlofluanid, and benomyl are the most effective fungicides for this purpose. Lenticel-rotting of apples (*Gloeosporium* spp.) during storage has been controlled in England and France by late summer sprays of captan, benomyl, and thiabendazole, which protect against or eradicate lenticel infections at that time of the year (75). Benomyl sprays applied to oranges more than one month prior to harvest prevented the postharvest development of stem-end rot arising from quiescent infections of *Diplodia* and *Phomopsis* in the button of the fruit (29). Brown-rot of peaches after harvest caused by *Monilinia fructicola* has been controlled by orchard sprays of benomyl applied 2–3 weeks before harvest, a treatment that eradicates quiescent infections (115, 149). Currently, the best control of *Phytophthora* brown rot of citrus fruit has resulted from sprays of fixed copper compounds applied to the lower skirt of the tree in the fall before the onset of the rainy season (198).

In recent years, several systemic fungicides have become available that can eradicate quiescent infections as well as protect against their establishment. Preharvest sprays of these materials can prevent the establishment of quiescent infections before harvest and reduce disease pressure, thereby improving considerably the effectiveness of postharvest fungicide treatments. The cost effectiveness of preharvest fungicide treatments to control postharvest diseases depends on the unit value of the crop and the ability to time a limited number of sprays to inactivate inoculum present during the period of crop susceptibility. In some cases, a few well-timed sprays of a systemic fungicide can prevent infection or eradicate inoculum of the pathogens responsible for postharvest diseases. A major problem in this approach to postharvest disease control is that selective fungicides such as benomyl may cause a proliferation of fungicide-resistant variants of the pathogen that cannot be controlled by postharvest treatment with benomyl or related fungicides.

Several fungicides have been developed over the past 15 years that can inactivate quiescent infections if they are applied to fruit after harvest. These systemic fungicides have the ability to inhibit development of latent infections of *Colletotrichum* spp. (46, 47, 140, 142) and to penetrate through the host cuticle to reach quiescent infection hyphae of *Alternaria* (161) and *Diplodia* and *Phomopsis* (24, 26).

Inactivation of Wound Infections

Many microorganisms responsible for postharvest diseases are unable to penetrate the surface barriers of the host. Mechanical and physiological injuries created during and after harvest are the usual sites of invasion by these "wound pathogens" which, as a group, cause the most devastating postharvest diseases. The strategy for controlling these diseases seeks to (*a*) eradicate incipient infections or pathogen propagules in susceptible injuries and (*b*) protect the surface of the perishable product against infection through superficial wounds created after application of the fungicide treatment. For many years, incipient infections on several fruit crops have been eradicated by the postharvest application of fungicides, usually water-soluble compounds that diffused into the injured tissue to inhibit the development of the pathogen there. Protection of the uninjured host tissue, on the other hand, requires a fungicide that can penetrate the plant cuticle to establish a deep-seated defense zone beneath the host surface (14, 70, 158, 163).

Two potential infection sites are common on harvested crops—the injury created by severing the crop from the plant, and natural openings such as lenticels and stomates. Natural openings in the host surface are a frequent route for infection, especially if the crop is handled or washed in water after harvest (10, 16, 102). Infection of the cut stem gives rise to crown rot of banana hands (181, 195); black rot of pineapples (78, 79); and stem-end rots of mangos, papayas, avocados, pears and green peppers (38, 113, 186, 189, 212).

Some random mechanical damage to the surface of perishable crops is inevitable in the course of harvesting, handling, and packaging, even when these operations are carried out with reasonable care. The severity of postharvest diseases induced by wound pathogens is proportional to the damage inflicted to the crop by rough handling after harvest (57, 107, 162, 185). Many fresh fruits and vegetables have physiological mechanisms (lignification, periderm formation, and phytoalexin production) for reducing the susceptibility of slightly injured tissue to invasion by pathogenic microorganisms (71). If wounded fruits and root crops are placed in an environment conducive to these reactions, the wounded tissues become highly resistant to infection within days or even hours (12, 13, 30, 124). Therefore, it is not essential that a postharvest fungicide persist at an injured site, but only that fungistatic action be exerted during the period when the wound is susceptible to infection. Postharvest treatments that cause a transient rise in the pH of wounded citrus peel (e.g. ammonia, aliphatic amines, and sodium bicarbonate) seem to function in this manner (61, 68).

Several investigators have demonstrated that sprays of dicloran applied to peach orchards one week before harvest reduced wound infection by *Rhizopus* after harvest (130, 148). Oranges sprayed with benomyl, thiophanate-methyl, and thiabendazole 30 days before harvest showed substantially less *Penicillium* mold two weeks after harvest (29, 98, 211). Sprays of benomyl and thiabendazole in pear and apple orchards reduced decay due to *Penicillium* and *Botrytis* in harvested fruit (15, 49). Although a postharvest treatment is usually more effective and efficient, a preharvest treatment is an appropriate strategy in situations where considerable harvest injury is anticipated (e.g. mechanical harvesting) and handling practices make postharvest treatments difficult to apply soon after harvest (162). Orchard sprays may be the best means to reduce decay of peaches that will be subjected to controlled ripening after harvest and oranges that will be degreened, since these practices often increase decay by wound pathogens (29, 148). Fungicides applied to the crop in the field before harvest should be selected with care since there is a significant risk that residues from the preharvest treatment will encourage the build-up of fungicide-resistant variants of the pathogen, and these will nullify all benefits of a postharvest treatment with the same or related fungicides (89, 120, 186).

Suppression of Disease Development and Spread

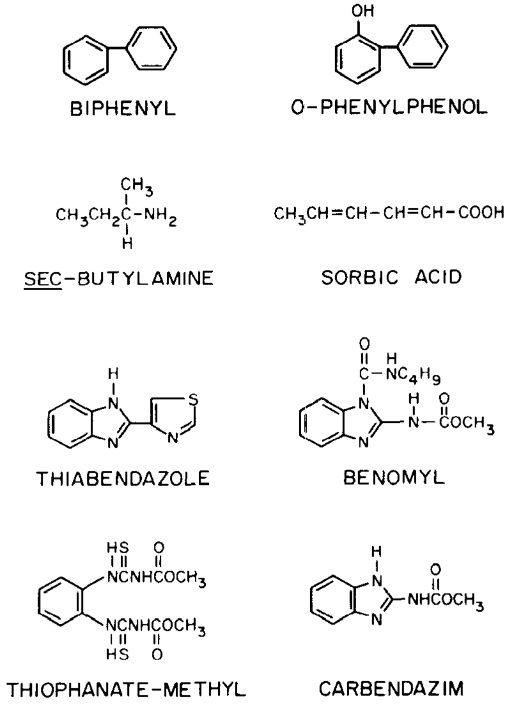
Although several postharvest fungicides have effectively controlled latent infections on tropical crops, lenticel infections on apples, and stem-end rots on citrus fruits, opportunities for suppressing the development of progressive infections by postharvest fungicide treatment are limited because superficially applied chemicals generally do not penetrate a significant distance into the infected host. Nonetheless, dicloran applied to peaches several days after inoculation retarded the expansion of established infections of *Rhizopus* (150, 203). Following a dip treatment, the fungistatic action of dicloran against *Rhizopus* was evident at a depth greater than 1 cm in the flesh of a peach (163). Fungistatic residues of benomyl have been measured several millimeters below the surface of superficially treated peaches (158), pears (14), and oranges (70). The degree of penetration of surface-applied chemicals appears to be determined by the surface characteristics of the crop, its maturity (44), and the lipophilicity of the applied compound. For example, benomyl penetrated pears better than thiabendazole (14) and oranges better than carbendazim (70).

Treatments involving cold, heat, irradiation, plant growth regulators, and modified storage atmospheres (high-CO_2, low-O_2, ethylene-scrubbed) that inhibit the onset of plant tissue senescence have successfully suppressed the progress of deep-seated fungal infections. These treatments have been discussed in detail elsewhere (56, 61, 71, 73, 77, 185).

The value of fresh fruits and vegetables may be reduced significantly by superficial fungal growth or by visible contamination by spores and other debris from adjacent diseased plant material, even though palatability and nutritional value are not affected. Soiling of citrus fruits with mold spores, superficial fungal growth on melon rinds, and moldy sepals on apples are devaluating conditions that can be controlled by postharvest fungicide treatments. *Botrytis, Rhizopus, Trichoderma, Sclerotinia, Phytophthora,* and other fungi can spread by contact from diseased to sound fruit during storage and long-distance transit. In fact, contact spread may account for the major losses caused by these pathogens. Incipient infections of *Botrytis* on grapes at the time of harvest may develop into pockets of decayed berries during long-term cold storage. The standard commercial practice is to fumigate grapes with SO_2 at ten-day intervals in order to suppress growth of *Botrytis* on the surface of diseased berries (146). Paper wraps impregnated with fungistatic chemicals have been used for many years to control spread of *Botrytis* and *Rhizopus* on several fruits and vegetables during long-term storage (61, 130). Recently, fruits have been individually wrapped in a heat-shrinkable polyethylene film that prevents the spread of diseases as well as the transfer of spores and debris from fruit to fruit in the same container (9, 72).

FUNGICIDE TREATMENTS

About 20 organic compounds have been extensively evaluated over the past 30 years as postharvest treatments to control diseases of perishable crops. The chemical structures of the most important compounds are shown in Figure 1. The chemistry and history of these compounds are given in *The Pesticide Manual* (210). First-generation postharvest fungicides [e.g. sodium *o*-phenylphenate (SOPP), dicloran, and *sec*-butylamine] are effective in preventing decay by wound-invading pathogens (e.g. *Penicillium* or *Rhizopus*) but have little effect on the development of latent and other deep-seated infections (60, 61). Fungicides developed since 1965 have shown a higher degree of



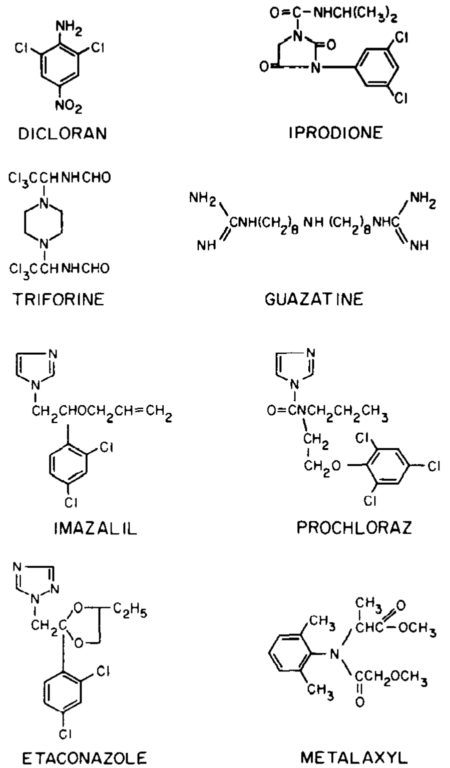


Figure 1 Postharvest fungicides

efficiency against latent infections, as well as protective and antisporulant action in controlling certain postharvest diseases. Few specific antibacterial compounds have been developed for postharvest use and, until recently, few fungicides were effective against Pythiaceous fungi, mucors, *Alternaria,* and *Geotrichum,* and diseases incited by these pathogens were difficult to control. Even compounds that showed in vitro activity against these fungi did not necessarily prevent disease development in the host, apparently because the fungicides were unable to penetrate to the sites of latent or established infections or the fungicides were inactivated by the host tissues.

The selection of an antimicrobial compound for a specific postharvest application depends upon (*a*) the sensitivity of the pathogen to the chemical agent; (*b*) the ability of the agent to penetrate through surface barriers of the host to the infection site; and (*c*) the tolerance of the crop to the chemical agent, from the standpoint of both phytotoxicity and any adverse effect upon the quality of the product. Fungicides may be applied to harvested products either in a gaseous state or mixed in a liquid formulation, depending on the physical and chemical properties of the fungicide and the compatibility of the treatment with the usual handling procedures for the crop. A fumigation treatment is preferred for the treatment of strawberries and other highly perishable commodities that are not normally treated with water after harvest. Sulfur dioxide is extensively used to fumigate grapes for control of *Botrytis* and is effective on raspberries as well. Fumigation of potatoes with *sec*-butylamine to control gangrene *(Phoma)* does not require wetting the tubers, which could predispose them to bacterial soft rot (127).

Today, most postharvest fungicides are applied in water-base formulations that are sprayed or flooded onto the harvested crop as it is conveyed mechanically through packing houses. Fungicides in water-base wax formulations and in hydrocarbon-solvent-base waxes are also often used. All of the organic fungicides shown in Figure 1 have been applied in these ways. Fungicides applied in water-base formulations to prevent wound infection may be divided into two categories according to their distribution on the surface of the treated product: (*a*) non-ionic water-insoluble compounds (e.g. thiabendazole) that are applied as uniform deposits over the entire surface of the treated product; (*b*) water-soluble salts (e.g. SOPP, *sec*-butylamine, and sodium carbonate) that are applied as relatively concentrated solutions (0.5–3.0%) in water. Aqueous solutions of these salts are absorbed by fruit wounds, but the intact cuticle is not permeable to such polar compounds. After treatment, the crop is rinsed lightly with fresh water to remove most of the fungicide from the surface of the fruit, but a significant residue remains at injured sites to inhibit growth of pathogens there. An advantage of uniform nonselective coverage of the crop with a fungicide is that the entire surface is protected to some degree against infections and injuries created after the treatment is applied. For example, benomyl-treated citrus fruits are difficult to inoculate through superficial wounds inflicted several days after the fungicide treatment is applied (24, 98). Apparently, benomyl enters the surface layers of the host where it inhibits development of *Penicillium* spp. in superficial wounds (70). To minimize the risk of phytotoxicity and excessive residues, some fungicides are applied to the crop surface and, after a minute or less, most of the compound is removed by a fresh-water rinse. However, a fungitoxic concentration is retained at wounded sites. Rinsing significantly reduces the phytotoxic potential of the treatment, but also reduces the antimicrobial effectiveness of the treatment (60).

Subtropical and Tropical Fruits

CITRUS The major postharvest diseases of citrus fruits are the stem-end rots incited by *Diplodia natalensis*, *Phomopsis citri*, and *Alternaria citri* and the wound pathogens, *Penicillium digitatum* (green mold), *P. italicum* (blue mold), and *Geotrichum candidum* (sour rot) (62, 65, 66). *Phytophthora* brown rot can be a serious problem in fruit harvested after a rainy period. *Diplodia* and *Phomopsis* stem-end rots are usually important only in fruit produced in areas with summer rainfall; the other diseases are ubiquitous in all citrus-producing areas. At the time of harvest, stem-end rot fungi are present as quiescent infections in the floral remnants (under the sepals) at the stem-end of the fruit. Incipient infections of *Phytophthora* may be present at any site on the surface of the fruit. Inevitably, the peel (pericarp) of the fruit is superficially wounded during harvesting and handling. These wounds may be inoculated with spores of *P. digitatum, P. italicum, G. candidum,* and other minor pathogens.

The principal strategies for control of postharvest diseases of citrus fruits are: (*a*) inhibit the development of latent infections of the stem-end rot fungi and incipient infections of *Phytophthora* in the fruit peel; (*b*) inactivate pathogen spores associated with fresh wounds; (*c*) protect the peel from infection through injuries inflicted during handling of the fruit after application of the postharvest fungicide; and (*d*) inhibit *Penicillium* sporulation on the surface of decaying fruit and the contact spread of several postharvest diseases.

Postharvest fungicides have played an important role in the development of distant markets for citrus fruits. Prior to 1960, the usual procedure for handling citrus fruits consisted of soaking the fruit in a warm solution (43°C) of a broad-spectrum fungicide, wrapping the fruit individually in biphenyl-impregnated paper, and promptly shipping the fruit in an iced railroad car to distant markets. The first fungicides utilized—borax, sodium carbonate, and sodium *o*-phenylphenate—had a broad antifungal spectrum and did not penetrate the fruit surface except at injured sites (potential infection sites for wound pathogens). The fruits were rinsed with fresh water after treatment because the fungicides were phytotoxic and the chemical residues remaining on the fruit from the relatively concentrated treating solution were unacceptable. These treatments were fairly effective against wound pathogens if applied to the fruit within 1–3 days after harvest, depending upon the ambient temperature (i.e. before the pathogen penetrated the peel beyond the immediate area of the wound). The treatments were only weakly effective against the stem-end rot diseases. The main purpose of the biphenyl (diphenyl) treatment was to inhibit *Penicillium* sporulation on decaying fruit; the treatment was only weakly effective in preventing infection by *Penicillium* and stem-end rot fungi. Biphenyl is not active against *Alternaria, Geotrichum,* or *Phytophthora*. The biphenyl treatment is widely used in export shipments today but is beset by problems associated with the odor and residues of biphenyl on treated fruits (66, 144, 202).

sec-Butylamine was developed as a postharvest fungicide for citrus fruits in the mid-1960s (67). This compound has a relatively narrow spectrum of antifungal activity and is mainly effective in preventing wound infection by *Penicillium* spp., although it also has some activity against stem-end rots (61).

sec-Butylamine is not active against *Geotrichum, Alternaria,* or *Phytophthora* and does not suppress *Penicillium* sporulation on decaying fruit. Fruit does not have to be rinsed after treatment with *sec*-butylamine because both the phytotoxicity and the mammalian toxicity of this compound are low. Therefore, *sec*-butylamine can be used more efficiently than SOPP, which must be rinsed after treatment; it can also be applied where rinsing after treatment is not possible. In California, harvested oranges may be drenched with a solution of 1% *sec*-butylamine (phosphate or HCl salt, pH 9) to protect harvest wounds from infection by *Penicillium* spp. during the period of ethylene degreening or during storage. The degreening operation is conducive to the development of *Penicillium* decay since it involves exposure of the fruit to a low concentration of ethylene (<10 ppm, v/v) for several days in a warm (22–29°C) humid environment. *sec*-Butylamine is also added to wax formulations applied to lemons before storage (15°C) to control *Penicillium* decay, but the treatment has no effect upon diseases caused by *Alternaria* or *Geotrichum*.

Pure *sec*-butylamine may be volatilized in the storage room or in a sealed package of fruit for fumigation action (68). The amine is bound as a salt in wounds on the fruit surface where it persists to inhibit the development of wound pathogens. Grierson & Hayward (88) developed a simple and effective method for fumigating citrus fruits in the field after harvest in developing countries where the fruits are not usually accumulated in a central packinghouse but are delivered directly from the grove to the market. An extensive series of trials in Florida showed that *sec*-butylamine fumigation of packaged citrus fruits before and during shipment was highly effective in reducing fruit decay during marketing (87).

The introduction of the benzimidazole fungicides benomyl, thiabendazole, carbendazim, and thiophanate-methyl (Figure 1) in the late 1960s was a milestone in development of postharvest fungicides to control citrus-fruit diseases. These compounds are not only highly effective in controlling wound infections by *Penicillium* spp., but certain members of this group are also uniquely effective because of their systemic properties. Thiabendazole and especially benomyl can penetrate the button of the fruit and arrest the development of *Diplodia* and *Phomopsis* that are quiescent there. In addition, benomyl has provided excellent protective action when fruits are treated before injury and inoculation. At high dosage rates, both compounds provide a protective barrier on the fruit surface that inhibits *Penicillium* sporulation on decaying fruit. This property is significant since the benzimidazole fungicides potentially offer an acceptable alternative to the biphenyl treatment for the control of fruit soilage.

When compared at equivalent concentrations, benomyl is usually more effective than the other benzimidazole fungicides. The biological superiority of benomyl in controlling fruit decays is probably a reflection of its ability to penetrate into the stem button and cuticle of the fruit (22, 24, 70). Carbendazim is almost equivalent to benomyl in preventing wound infection by *Penicillium* and is more effective in this respect than thiabendazole (28, 126, 154). However, carbendazim is inferior to benomyl for the control of *Penicillium* sporulation on decaying oranges (70) and for protecting the fruit against infection of wounds inflicted after fungicide treatment (28). Benomyl penetrated the cuticle of the orange better than carbendazim and inhibited the hyphae of *Penicillium* ramifying in the flavedo layer (exocarp) of the peel (70). Brown (22) reported that benomyl penetration into the peel could be substantially increased by the addition of emulsified oil to the benomyl suspensions. Thiophanate-methyl slowly undergoes a cyclization reaction on the plant surface to form carbendazim. Thiophanate-methyl has compared favorably with benomyl and thiabendazole for control of *Penicillium* decay and *Diplodia* stem-end rots in most trials (123, 154).

The benzimidazole fungicides are not active against *Geotrichum, Alternaria,* or *Phytophthora*. *Penicillium italicum* is somewhat less sensitive to the benzimidazole fungicides than *P. digitatum;* therefore, blue mold dominates on oranges treated with low concentrations of these compounds (94) and on lemons in storage rooms where benzimidazole-treated fruit are being recycled all season. In addition to their effectiveness in controlling decay, thiabendazole and benomyl have reduced chilling injury on grapefruit stored at temperatures that normally causes cold-induced pitting of the fruit (119, 169, 201).

Although dipping citrus fruits in an aqueous suspension of a benzimidazole fungicide usually provides the most effective decay control, this application method has several major drawbacks as a commercial procedure. Today, benzimidazole fungicides are usually applied as a non-recovery spray in water or in a wax formulation to fruit rotating on brushes (24, 184). The more effective application methods thoroughly wet the fruit with benzimidazole suspension. Suspensions of thiabendazole in water have provided better decay control than suspensions in wax emulsions (28, 99, 155). Benomyl in water-wax formulations has provided control of *Diplodia, Phomopsis,* and *Penicillium* that is equivalent to benomyl in water only (28, 184). Brown (28) showed that benzimidazole fungicides (benomyl, thiabendazole, and carbendazim) were more effective in water than in wax formulations against stem-end rots on oranges that were degreened 24–72 hr. Benomyl and thiabendazole suspended in water have provided better control of stem-end rots than formulations in an organic solvent wax (184). Presumably, the solvent evaporates before the fungicide can move under the button of the fruit where the pathogen lies in a quiescent state.

Although thiabendazole and carbendazim are stable in formulations, benomyl and thiophanate-methyl are chemically more reactive. At concentrations used for fruit treatment (>500 mg/liter), benomyl was stable for several days in tap water (11). However, at the same concentrations in a commercial wax formulation, benomyl decomposed extensively to carbendazim within 8 hr at room temperature (69). In an alkaline environment (pH >8.0), the substituents attached to the benzimidazole nucleus of benomyl react to form 1,2,3,4-tetrahydro-3-butyl-2,4-dioxo-*s*-triazino(α)-benzimidazole, which is not effective against citrus-fruit decays (69, 204). Since benomyl is a more effective postharvest fungicide than its breakdown products, benomyl should be stabilized to the maximum extent possible. Several methods have been used to accomplish this in practice: (*a*) Benomyl is suspended in water and applied to the fruit; (*b*) fresh benomyl is added to the wax formulation once each day; and (*c*) a concentrated suspension of benomyl in water is injected into the water-wax delivery system immediately before spraying onto the fruit.

The intensive and continuous use of biphenyl, SOPP, thiabendazole, benomyl, and *sec*-butylamine has created a serious worldwide problem of fungicide resistance in *Penicillium digitatum* and *P. italicum* (36, 53, 63, 74, 76, 110, 135). *Penicillium* isolates that are resistant to one fungicide are usually cross-resistant to structurally related compounds—e.g. biphenyl and SOPP; thiabendazole, benomyl, carbendazim, and thiophanate-methyl. Treatment of fruit with a fungicide from one of these groups before storage usually results in the selection and proliferation of fungicide-resistant variants in the pathogen population so that a structurally related fungicide cannot be used effectively on the same lot of fruit after storage. For example, lemons in California may be washed in a bath of SOPP; waxed with a formulation containing 2–4,D and thiabendazole, benomyl, or *sec*-butylamine; and then stored at 15°C for several months. The selection pressure of the SOPP residue on the lemons during storage results in the proliferation of *Penicillium* isolates resistant to SOPP/biphenyl; these strains are then not controlled by SOPP or biphenyl, which are standard treatments applied after storage. Similarly, the application of thiabendazole or benomyl in wax before storage selects for benzimidazole-resistant strains that cannot be controlled by treatment with these fungicides after storage. A serious problem of fungicide-resistance frequently develops when lemons or oranges are packed but not shipped. Such wares remain in cold storage for several weeks before they are returned to the packinghouse, where decayed fruits are removed from the carton prior to shipment. Fungicide-resistant *Penicillium* isolates, selected during storage by fungicide residues on the fruit, contaminate all the fruit passing through the packinghouse, resulting in a great reduction in the effectiveness of the final fungicide treatments.

The management of the fungicide resistance problem is currently an area of active research, and some possible strategies have been discussed in detail elsewhere (8, 63, 74). Two approaches dominate the development of an overall strategy: (*a*) sanitation measures and antisporulant treatments to suppress the spore population to a low level; (*b*) fungicide regimens that do not encourage the proliferation of fungicide-resistant strains in the spore population. Fungicides are applied to the fruit before storage that will not encourage the proliferation during storage of *Penicillium* strains resistant to the fungicides applied after storage. Imazalil, prochloraz, and etaconazole (discussed below) belong to a class of compounds that inhibit the biosynthesis of ergosterol, an essential component of the fungus cell membrane. Generally, "resistant" mutants show only a low level of tolerance to these fungicides and are often less virulent than the wild-type strains of the pathogen. On the basis of these observations, some investigators find it improbable that a practical problem of resistance will arise involving this class of fungicides.

Sorbic acid (Figure 1) has been used in commercial citrus packinghouses to control *Penicillium* decays, usually when isolates of the pathogen are resistant to the benzimidazoles, SOPP, and *sec*-butylamine. A nonrecoverable spray of potassium sorbate (2%) solution provided control of *Penicillium* molds and *Phomopsis* stem-end rot that was equal to that provided by SOPP (183). The addition of 2% potassium sorbate to a water-base wax formulation containing thiabendazole or benomyl brought about a significant reduction in *Penicillium* decay in commercial shipments of lemons and grapefruits from packinghouses that were contaminated with benzimidazole-resistant *Penicillium* spores (147). However, Gutter (95) concluded from his tests with inoculated fruit that potassium sorbate alone did not substantially reduce the incidence of green mold but rather delayed the onset of the disease for 1–2 weeks. Sorbic acid must be viewed as a weak postharvest fungicide in comparison with thiabendazole and benomyl; nonetheless, among the arsenal of postharvest fungicides, it can be used when others fail owing to fungicide-resistant *Penicillium* isolates.

Imazalil (Figure 1) was the first ergosterol biosynthesis inhibitor (EBI) to be used as a postharvest fungicide. Imazalil has been used commercially in several citrus-producing areas of the world for the past five years and was registered in the United States in 1984 for treatment of citrus fruits after harvest. The antifungal spectrum of imazalil is qualitatively similar to that of the benzimidazoles. Imazalil also has activity against *Alternaria*, but it is less effective than benomyl for control of *Diplodia* and *Phomopsis* stem-end rots (26, 28). Imazalil controls *Penicillium digitatum* and *P. italicum* on citrus fruits, including isolates that are resistant to thiabendazole, benomyl, SOPP, and *sec*-butylamine (97, 103, 116, 122, 133, 134). Water solutions of imazalil control *Penicillium* decay by curative, protective, and antisporulant actions that are at least equal, and perhaps slightly superior, to those of benomyl (122). Imazalil has been applied as dip, drench, and spray (97, 116, 122, 134, 200). The effectiveness of imazalil is reduced in a water-wax formulation; the concentration must be doubled in water-wax formulations for activity equivalent to that in water alone (28, 31). The poor eradicant action of imazalil in a water-wax formulation was related to the reduced movement of the fungicide in the wax film and the limited penetration of the compound into the fruit peel. Formulations of imazalil in solvent-base waxes have performed erratically (116).

Several investigators reported that imazalil was slightly less effective than thiabendazole and benomyl against *Phomopsis* stem-end rot (26, 182), while others found equivalent performance of imazalil and the benzimidazoles against this disease (34, 134). Benomyl appears to give more consistent control of *Diplodia* stem-end rot than imazalil, especially when fruit with latent infections are degreened for 2–3 days before treatment with a water-wax formulation containing either benomyl or imazalil (26, 28). Most investigators have reported that imazalil is not effective against sour rot caused by *Geotrichum candidum* (25, 64, 116, 134, 168, 182). Reports conflict on the effectiveness of imazalil against *Alternaria* rot (26, 170, 182, 200).

Guazatine (Figure 1) is a broad-spectrum water-soluble diguanide that can eradicate incipient infections of *Penicillium* spp. and *Geotrichum*. Treatment of citrus fruits with guazatine (250–1000 mg/liter) one day after inoculation eradicated incipient infections of green and blue mold, including isolates resistant to benzimidazole fungicides (27, 64, 105, 121, 199, 205). Guazatine did not protect treated fruit against subsequent infections at new inoculation sites, nor did high dosages of the fungicide (2000 mg/liter) inhibit sporulation of *Penicillium* on diseased fruits. Guazatine was the first fungicide shown to have strong activity against incipient infections of *Geotrichum* (sour rot). Several investigators demonstrated that guazatine (250–1000 mg/liter) applied within 24 hr after inoculation provided excellent control of sour rot (25, 64, 121, 165, 168, 199). Unfortunately, strains of *Penicillium italicum* resistant to guazatine have been isolated recently (106, 205). Guazatine was not effective against *Alternaria, Phomopsis,* or *Colletotrichum* on mandarins (121) but showed significant activity against *Diplodia* stem-end rot when drenched over oranges before degreening (27). However, benomyl (600 mg/liter) was much more effective against *Diplodia* stem-end rot than guazatine (1000 mg/liter) when both treatments were applied as a nonrecovery spray after degreening the fruit. Guazatine has been applied commercially to citrus fruits in Australia for several years (199), and residue tolerances have been established in Sweden, Australia, and the Federal Republic of Germany.

Prochloraz (Figure 1), an imidazole EBI fungicide, has a spectrum of antifungal activity qualitatively similar to that of imazalil. Prochloraz (1000 mg/liter) eradicated incipient infections of *Penicillium digitatum* and *P. italicum* to about the same degree as benomyl and imazalil treatments (26, 27, 200). Prochloraz controlled isolates of *Penicillium* that were resistant to benomyl and thiabendazole. At 500–1000 mg/liter, prochloraz showed remarkable anti-sporulation action against *Penicillium,* at least equivalent to that provided by benomyl and imazalil (200). Prochloraz is moderately effective against *Alternaria* (stem-end rot and black rot), but like imazalil, it is not effective against sour rot (26, 200). Prochloraz reduced the incidence of *Diplodia* and *Phomopsis* stem-end rots, but the treatment was less effective than benomyl, imazalil, or etaconazole (26, 27).

Etaconazole (Figure 1), a triazole EBI fungicide, provided outstanding control of sour rot and *Penicillium* decay, including infections by benzimidazole-resistant isolates. Etaconazole (250–1000 mg/liter) applied within 24 hr after inoculation eradicated incipient infections of *Penicillium* spp. and *Geotrichum* (sour rot) (25, 27, 64, 168). At these concentrations, etaconazole strongly suppressed *Penicillium* sporulation on diseased fruits and protected treated fruits from infections through new wounds created after application of the treatment (64, 95). Etaconazole is moderately effective against *Alternaria*, *Phomopsis*, and *Diplodia* stem-end rots. Etaconazole (200 mg/liter) applied as a dip treatment to grapefruit (naturally inoculated with *Phomopsis*) controlled stem-end rot as well as imazalil during storage of the fruits for 56 days at 12°C (34). Brown (26, 27) reported that etaconazole reduced the incidence of *Diplodia* and *Phomopsis* stem-end rots in artificially inoculated fruits, but its effectiveness was less consistent than that of benomyl. Etaconazole was equivalent to prochloraz in providing a moderate reduction in the incidence of *Alternaria* stem-end rot. Obviously, both compounds are superior to benomyl and thiabendazole, which have no effect on *Alternaria* rots. Etaconazole is the most outstanding postharvest fungicide to date for citrus fruits, especially for arid subtropical production areas. This fungicide controls the major fungal pathogens responsible for decay of citrus fruit after harvest. The closely related fungicide propiconazole (210), which differs from etaconazole in that it has a propyl substituent on the dioxolan ring (Figure 1), has antifungal activity similar to that of etaconazole (64).

Metalaxyl (Figure 1) is uniquely effective in eradicating incipient infections of *Phytophthora* but has no influence on the development of other postharvest diseases. Treatment of citrus fruits with metalaxyl (1–2 g/liter) in water or in a water-wax formulation prevented or delayed the development of brown rot on citrus fruits (40, 42, 43, 64). The metalaxyl treatment also suppressed the growth of *Phytophthora* on the fruit surface and prevented contact-spread of the disease on grapefruit stored for 3 months at 11°C. Cohen (42) demonstrated that a water-wax formulation containing metalaxyl and etaconazole controlled *Penicillium* decay, sour rot, and brown rot.

Fosetyl aluminum (phosethyl-Al, 2–4 g/liter) applied to oranges after harvest provided protective and curative action against infection by *Phytophthora parasitica*, including an isolate resistant to metalaxyl (83). Treatment of lemons inoculated with *P. citrophthora* with 1 g/liter fosetyl aluminum gave a slight but significant reduction in the incidence of brown rot (64). Fosetyl aluminum also reduced green mold *(Penicillium digitatum)* significantly (83, 96).

BANANA The banana is the only tropical fruit that is exported in large quantities. The greatest concentration of production is in tropical America, and the principal markets are in North America, Europe, and Japan. The transit time is 5–20 days (13–14°C) followed by 2–7 days at higher temperatures for ripening and marketing (132). Until 1960, Gros Michel, the principal commercial variety, was shipped "on stem"—the least expensive and most expedient method of handling. However, the Gros Michel plant was highly susceptible to Panama disease (*Fusarium oxysporum* f. sp. *cubense*) and was replaced in the early 1960s by cultivars of the Cavendish group, which are highly resistant to fusarial wilt but more susceptible to scarring and bruising during shipment (109, 195). This necessitated a change from the traditional "on stem" shipping method to packaging of individual hands in fiberboard cartons lined with polyethylene film to minimize the scarring and bruising of the fruit during shipment (109, 181, 195). At the packing station, hands are cut from the stem and floated in water to permit latex flow from the cut crown, treated with a fungicide, and packed into fiberboard boxes. Application of a fungicide soon after dehanding is essential to prevent infection of the cut crown surface. The development of suitable fungicide treatments to control crown rot was critical to the successful conversion from shipping bananas "on stem" to shipping hands in fiberboard boxes. Even today, crown rot is the most serious postharvest problem with bananas. This disease is difficult to control because of the complex of fungal pathogens involved and the difficulty in reaching potential infection sites with an effective fungicide. While the banana hands are floating in water, spores of the pathogens may be drawn into vascular elements of the crown tissue to a depth of several millimeters, where they may produce deep-seated infections that cannot be eradicated easily by superficial fungicide treatments (86). Several pathogenic fungi have been isolated from decaying crown tissue—*Cephalosporium, Verticillium, Fusarium, Botryodiplodia, Colletotrichum, Deightoniella,* and *Ceratocystis* (86, 90, 92, 174, 195). *Ceratocystis* is only occasionally isolated from rotted crown tissue of fruit from Ecuador and Columbia. The crown rot pathogens commonly grow saprophytically and sporulate on senescent flower parts and foliage in the plantation. The spores are carried by wind and rain-splash to the flower parts and developing hands. The harvested fruit carry the spores into the dehanding tank, resulting in the inoculation of the cut crown tissue of many hands as they are floated through the water bath (175, 176, 195). Because crown rot severity increases with transit time, the disease is more serious in fruit marketed in Europe than in US shipments. The disease spreads rapidly throughout the crown during ripening, and occasionally the decay extends into the pedicels of the fingers (181).

Other diseases that may create problems in green bananas packed in fiberboard boxes are wound infection by *Colletotrichum* on the pedicel of the finger ("neck"), and fruit spots caused by infections of this fungus at scars and abrasions on the fingers (nonlatent anthracnose) (90, 181, 195). Pitting caused by *Pyricularia grisae* is a serious postharvest fruit spot that arises from latent infections of this fungus. Substantial losses due to *Botryodiplodia* finger rot sometimes occur in fruit held at a high temperature in transit for more than 14 days (195). Squirter disease, a finger rot arising from infection by *Nigrospora* through the cut pedicel, is a serious disease of banana fingers packed as "singles" in New South Wales (164).

Reducing the inoculum level and protecting wounds against fungal infection are the major strategies for control of postharvest diseases of bananas (177, 181, 195). Trash leaves, flower bracts, and transition leaves—the major sources of crown rot inoculum—are removed at the time fruit are bagged in the field. In Central America, bunches are often sprayed or dusted with mancozeb before bagging to prevent infection of the peel by *Pyricularia grisae* (181). The dehanding tank is recognized as the major site of crown rot inoculation (175, 176). Several investigators have studied the effectiveness of chlorinating the dehanding tank water (5, 85, 176). Hyaline thin-walled pathogen spores are sensitive to chlorine, but appressoria and conidia with dark thick walls are not killed by practical chlorine treatments (85). A major problem with chlorination is the maintenance of a sufficient level of active chlorine in the presence of latex and organic debris in the water (181, 195). Slabaugh & Grove (181) cite unpublished studies showing that chlorinating the dehanding tank water did not reduce the incidence of crown rot, even when the active chlorine was maintained at an effective level. They concluded that the systemic fungicide thiabendazole was far more effective than chlorination for the control of crown rot. Shillingford (176) reported that a thiabendazole dip treatment (400 mg/liter) did not adequately control wound anthracnose or crown rot on banana hands that had been first immersed in water contaminated with inoculum of the pathogens. He found that quaternary ammonium compounds and formaldehyde were superior to hypochlorite for eradicating the pathogen spores in vitro.

The major postharvest diseases of bananas have been efficiently controlled in most instances by dip or spray treatment of the detached hands with suspensions of 200–1000 mg/liter thiabendazole (7, 33, 80, 128, 129, 174, 175, 181) or 100–500 mg/liter benomyl (33, 80, 91, 128, 129, 151, 164). In providing control of crown rot and anthracnose, carbendazim and thiophanate-methyl were superior to thiabendazole and only slightly inferior to benomyl (80, 81, 90, 93, 129). The practice of shipping bananas in sealed polyethylene bags at ambient temperatures to delay ripening and reduce weight loss is dependent upon treatment of the fruit with thiabendazole before packing, to control decay (172).

Benomyl appears to penetrate into the cut crown tissues and cuticle to a limited extent to inhibit the development of pathogen spores in the vessels of the crown tissue (86, 177) and to eradicate incipient infections (91, 128). However, subcuticular penetration of benomyl would not be required to eradicate latent infections of *Colletotrichum* which arise from appressoria situated on the surface of the cuticle (141). Griffee & Burden (91) found that four benomyl sprays applied to the fruit in the plantation controlled the development of latent anthracnose infections after harvest but had no effect on the development of the pathogen in wounded tissue or of crown rot. They recommended against the use of benomyl as a preharvest spray because benomyl-resistant isolates of *Colletotrichum* were recovered from benomyl-sprayed fruit. Furthermore, a single postharvest treatment with benomyl (250 mg/liter) provided excellent control of both wound infection and latent *Colletotrichum,* as well as crown rot.

According to Slabaugh & Grove (181), the control of banana crown rot deteriorated dramatically during 1977–1979 in areas where the plantations were sprayed with benomyl for leaf spot control. The reduced control was due to the build-up of benzimidazole-resistant variants of the crown rot pathogens. Apparently, the benomyl sprays exerted a heavy selection pressure on the pathogen population since the crown rot fungi commonly colonize and reproduce on dead plant material in the plantation. This selection pressure produced a change in the pathogen population, resulting in the frequent appearance of benomyl-tolerant isolates of *Fusarium roseum* cult. *semitectum* and *Acremonium* sp. as the principal pathogens responsible for the crown rot (181; R. H. Stover, personal communication). The benzimidazole fungicides are rotated with nonbenzimidazole fungicides for sigatoka control in some Central American banana plantations in an effort to reduce the selection pressure for benzimidazole-resistant pathogens (137). Fortunately, benzimidazole resistance in crown rot and *Colletotrichum* rots can be overcome by treatment of the fruit with imazalil (500 mg/liter) after harvest (82). Imazalil is approved for use on bananas in major importing countries and may be more convenient in practical use because it is considerably more water soluble than the benzimidazole fungicides.

MANGO The mango is a climacteric fruit that is harvested in a mature green state and may be stored for 2–3 weeks at 10–12°C before ripening. The most serious postharvest diseases are anthracnose, developing from latent infections of *Colletotrichum* initiated in the field, and stem-end rots (*Diplodia* and *Phomopsis*), which arise by invasion of the cut stem after harvest. Appressoria on the fruit surface appear to be the main latent stage of anthracnose (50). Black spot, which develops from latent infections of *Alternaria alternata* in the lenticels, is the most serious postharvest disease of the mango in Israel (161).

The major strategies for control of postharvest mango diseases are regularly scheduled sprays in the field to reduce latent infections of *Colletotrichum* (136) or *Alternaria* (161) and treatment of the fruit with hot water/fungicides after harvest to eradicate the remaining latent infections and the stem-end rot pathogens. Anthracnose can be controlled by submerging the green fruit after harvest in water at 55°C for 5 min. However, this treatment may slightly injure the fruit, especially if they are stored at a low temperature (12°C) after treatment (187). The heat treatment may also accelerate the change in peel color from green to yellow (140) and remove natural wax from the fruit surface, reducing its luster and accelerating shrivelling. Spalding & Reeder (187) reported that anthracnose was controlled and the storage life of the fruit was extended by adding thiabendazole or benomyl (1000 mg/liter) to the hot water. More recent investigations in Florida (189) and Australia (139) showed that benomyl (500–1000 mg/liter) in water at 52°C gave satisfactory control of anthracnose with less heat damage to the fruit. The hot water benomyl/thiabendazole treatments have not provided satisfactory control of stem-end rot (19, 187). The benomyl dip at ambient temperatures has given erratic results in several investigations (139, 143, 187). The reason for this variability is not clear since the superficial appressoria are reputed to be the latent form of the disease (50).

Spalding (186) isolated benzimidazole-resistant variants of *Colletotrichum, Diplodia,* and *Phomopsis* from decaying mangos in Florida packinghouses. Presumably, the fungicide-resistant isolates were selected by the intensive use of benomyl to control anthracnose on the fruit in the grove (136). Postharvest applications of imazalil and etaconazole gave good control of anthracnose and stem-end rots during storage and ripening of the fruit; but benomyl, thiabendazole, and thiophanate-methyl were ineffective, presumably because benzimidazole-resistant isolates of the pathogen were present as latent infections on the fruit at the time of harvest (186). A postharvest treatment of iprodione (1500 mg/liter) substantially reduced the incidence of *Alternaria* black spot on mangos in Israel (161).

PAPAYA The papaya and mango are handled similarly after harvest except that the papaya is harvested after color break. The fruit can be stored at 8°C for 4 weeks; surface transportation from Hawaii to the United States mainland requires 7–18 days at 10–15°C (2). The major postharvest diseases are anthracnose and chocolate spot (both arising from latent infections of *Colletotrichum*) and stem-end rots caused by *Mycosphaerella (Ascochyta), Phomopsis,* and *Botryodiplodia* (112). Fruit surface rots caused by *Alternaria, Phytophthora, Rhizopus, Stemphylium,* and *Mycosphaerella* may also diminish the postharvest life and appearance of the fruit.

Colletotrichum spores splash onto the fruit in the plantation and germinate to form an appressorium. An infection hypha from the appressorium penetrates through the cuticle and forms a latent infection in the immature fruit. Infection usually occurs in an early stage of fruit development (39, 58). The symptoms of anthracnose develop when the fruit begin to ripen after harvest. All the postharvest diseases except *Rhizopus* can be traced to field infection. The stem-end rot diseases arise from the infection of the cut stem at the time of harvest and through cracks at the fruit's stem-end (38). The standard treatments for control of postharvest diseases of papayas are field sprays of mancozeb, chlorothalonil, or benomyl applied to the fruit on a 10–14-day schedule throughout the growing season, and a hot-water dip after harvest. The biweekly orchard sprays control latent infections of *Colletotrichum* and infection by other fungi such as *Phytophthora* and *Alternaria*. The field sprays also reduce the level of inoculum of *Mycosphaerella*, *Botryodiplodia*, and other wound pathogens (2, 18, 112). These fungicide sprays are essential to reduce disease pressure on the fruit at the time of harvest; the postharvest hot-water treatment alone cannot provide satisfactory control of fruit decay (2, 3).

The standard hot-water treatment (48°C, 20 min) has been used successfully in Hawaii for 20 years to control anthracnose, stem-end rots, and incipient infection of *Phytophthora* (1, 3). The hot-water treatment also reduces the ethylenedibromide exposure time required for satisfactory control of fruit fly. Nonetheless, several problems associated with the hot-water treatment have been recognized—delayed color development and incipient heat injury accompanied by an increase in *Stemphylium* rot (47, 84) and *Rhizopus* rot (20). The hot-water treatment may not give adequate control of *Phytophthora* rot if the fruit have a large number of incipient infections, especially if they are more than 24 hr old (3). Brodrick et al (20) observed that hot water–treated papayas tended to shrivel in storage, but this could be prevented by applying a wax to the fruit after the hot-water treatment. The 20-min hot-water treatment is excessively long for large-scale packing operations, and interest has developed in reducing the time required by adding fungicides or increasing the water temperature (20, 140). A hot water–spray treatment (54°C, 3 min) has been developed that is effective in controlling anthracnose and stem-end rots (46, 111). Thiabendazole and benomyl dips (500 mg/liter) at ambient temperatures greatly reduced *Colletotrichum*, *Ascochyta*, and *Gloeosporium* rots that developed on papayas during ripening at 22–24°C for 8 days (18). Investigators in Hawaii (46, 47) evaluated thiabendazole as a supplement to the hot-water treatment which, alone, did not adequately protect papayas that were shipped by surface transport to mainland US markets. Thiabendazole (4 g/liter) alone was as effective in reducing stem-end rots and anthracnose as either a hot-water dip or the hot water–spray treatment. SOPP was not effective. They recommended a hot-water spray followed by a thiabendazole spray (water or wax) as the best method for control of decay in papayas destined for long-distance surface shipments. The hot water–dip treatment was not recommended because it increased *Stemphylium* decay, which was not controlled by thiabendazole (46, 47). Muirhead (140) evaluated solutions of guazatine, etaconazole, prochloraz, carbendazim, and imazalil at ambient temperature for control of papaya decays. Only prochloraz (1000 mg/liter) gave outstanding control of anthracnose and stem-end rots.

PINEAPPLE The pineapple is a nonclimacteric fruit and does not continue to ripen after harvest. The fruit is usually harvested when the surface color is between "color break" and quarter yellow, depending upon the expected time in transit to the market. The fruit may be held at 7°C during a 10–20 day shipment (1, 132). Black rot, incited by *Ceratocystis paradoxa,* is the most important postharvest disease of the pineapple. The fungus enters the fruit through the cut stem-end or through wounds inflicted to the sides of the fruit during handling and packing. The disease develops rapidly at tropical temperatures. *Cladosporium, Penicillium,* and *Trichoderma* also invade wounds in harvested fruit and are known as surface molds.

For several decades, fungicides (e.g. benzoic acid and salicylanilide) have been applied to the cut stem or to the surface of the pineapple after harvest (60). Frossard (78, 79) reported that black rot could be controlled by applying thiabendazole or benomyl (1.5–3.0 g/liter) to the cut stem within 4 hr after harvest. The treatments did not give good control of infection at injuries on the side of the fruit. Cho et al (41) found that benomyl (500 mg/liter) gave better control of black rot on inoculated fruit than thiabendazole (1000 mg/liter). SOPP was not effective, although this fungicide has been the standard postharvest treatment in Hawaii for many years (1). Recently, the postharvest application of a wax has become popular because the treatment controls internal browning and water loss from the fruit. Thiabendazole or benomyl may be added to the wax formulations, although they were less effective when mixed with a wax formulation than when applied in water (41).

AVOCADO Avocados are harvested and shipped in the preclimacteric state. The fruit of most varieties is stored at 10–12°C to avoid chilling injury, but cold-tolerant cultivars such as Fuerte can be held at 4–7°C for 3–4 weeks (132). The storage period can be extended in a controlled atmosphere (2% O_2, 10% CO_2) at 7°C for 6–8 weeks (188). The most important postharvest diseases of avocado fruits are anthracnose *(Colletotrichum), Dothiorella* rot, and stem-end rots caused by *Botryodiploida, Alternaria,* and *Dothiorella* (52, 142, 188). The infection of fruit in the grove by *Colletotrichum* is similar to that described for bananas and oranges; superficial appressoria appear to be the latent stage of the pathogen on the fruit at the time of harvest (17). *Dothiorella* may be quiescent in the lenticels. Both diseases develop progressive lesions as the fruit begin to soften. Traditionally, anthracnose and *Dothiorella* rots have been controlled by fungicide sprays in the grove (e.g. fixed coppers, benomyl, captafol, and triadimefon) (52, 157). Stem-end rot was controlled by dipping avocados in thiabendazole (1.5–2.0 g/liter) after harvest (212). After three years of commercial use in Israel, the thiabendazole treatment of avocados began to fail because *Alternaria* spp. replaced *Diploida* as the major stem-end rot (212). More recent trials in South Africa have shown that postharvest dips of thiabendazole (1.8 g/liter) and benomyl (0.5 g/liter) in a wax formulation reduced *Dothiorella* and *Colletotrichum* rots significantly (51). The wax treatment prolonged the shelf life of the fruit for two days. In Australia, procloraz dips (0.25–1.0 g/liter) gave excellent control of anthracnose and stem-end rots (142). Carbendazim and etaconazole controlled stem-end rots, but not anthracnose.

MINOR TROPICAL FRUITS The guava is a soft-skinned fruit susceptible to infection by a variety of wound-invading fungi: *Colletotrichum, Phoma, Penicillium, Pestalotia, Aspergillus,* and *Phomopsis* stem-end rot (180, 208). A benomyl (2–3 g/liter) dip treatment at ambient temperatures controlled natural decay and infections on wound-inoculated fruit (180). Wills et al (208) reported, however, that benomyl (3.0 g/liter) at ambient temperature did not adequately control decay of naturally inoculated fruit, although a benomyl (0.5–2 g/liter) dip at 48–50°C for five minutes was highly effective in decay control. A heated guazatine solution was less effective and was phytotoxic to the fruit. Carbendazim and triforine, both at 1.25 g/liter, provided good control of *Aspergillus* wound infection (6).

Litchi fruit are susceptible to infection after harvest by several of the fungi that also attack the guava (159, 173). Postharvest decay was reduced by treatment of the fruit with a wax formulation containing SOPP (2.5 g/liter) (159). Scott et al (173) found that browning and weight loss of the litchi could be controlled by packaging the fruit in a plastic film, but pretreatment with benomyl (0.5 g/liter, 52°C, 2 min) was required to control decay under the high-humidity environment within the plastic film.

Diplodia, Pestalotia, and *Colletotrichum* cause postharvest diseases of loquat fruits. Benomyl (600 mg/liter) applied at ambient temperature gave better control of decay than did thiabendazole, imazalil, or SOPP treatments (101).

CONCLUSIONS

The development of the benzimidazole fungicides in the late 1960s provided a conceptual breakthrough in postharvest disease control. Prior to that time, the postharvest treatment of fruit crops was limited almost entirely to the application of nonselective fungicides soon after harvest to inactivate wound pathogens. The benzimidazoles demonstrated the potential of high-potency selective fungicides that could penetrate into fruit tissues to prevent the development of quiescent infections and other subsurface inocula without injuring host cells or interfering with the induction of defense mechanisms. The benzimidazoles and other highly active fungicides (e.g. dicloran, imazalil, prochloraz, etaconazole, and guazatine) could enter injured tissue and, in some cases penetrate through the intact cuticle, protecting the fruit against subsequent infection, suppressing the expansion of visible lesions, and inhibiting fungus sporulation and disease spread. Some of these compounds are remarkably effective in controlling crown rots and stem-end rots, apparently because they can penetrate into the stem tissues or are drawn into the vascular elements of the cut stem. The development of systemic fungicides during this period was fortunate since these treatments supported major changes in the packaging, postharvest handling, and marketing of citrus fruits, bananas, and to a lesser extent other tropical fruits.

The successful application of the benzimidazole fungicides for the control of several major postharvest diseases has magnified the importance of pathogens insensitive to this class of fungicides: *Alternaria, Stemphylium, Acremonium, Geotrichum, Phytophthora,* mucors, and benzimidazole-resistant variants of *Penicillium, Botrytis, Fusarium,* and *Diplodia* that were selected by the intensive use of these fungicides. In fact, some investigators have reported that postharvest treatment with benzimidazole fungicides may increase the severity of diseases caused by benzimidazole-insensitive pathogens.

Since the mid 1970s, several compounds that inhibit ergosterol biosynthesis ("EBIs") in sensitive fungi have been investigated for many of the same postharvest applications as the benzimidazoles—i.e. for eradication of quiescent infections and for disease suppression. Imazalil, prochloraz, and etaconazole/propiconazole have provided good control of pathogens that are not inhibited by the benzimidazole fungicides. Imazalil is applied commercially to citrus fruit and bananas after harvest to control pathogen species and variants that are resistant to the benzimidazoles. The value of this treatment was demonstrated experimentally in the control of postharvest diseases of mangos induced by fungicide-resistant isolates of several pathogens, isolates that had been selected by the intensive application of benzimidazole fungicides in the plantation. In vitro studies have shown that resistant isolates are rare in populations of EBI-sensitive pathogens and that "tolerant" variants usually exhibit diminished pathogenic fitness. These observations suggest that resistance to EBI fungicides may develop slowly, if ever, in pathogen populations, even under high selection pressure. This supposition has been borne out thus far by experience: No episode of practical resistance to imazalil has been reported after three years of commercial use of this fungicide on citrus fruits under conditions that exert high selection pressure for the emergence of resistant isolates of *Penicillium*. The EBI fungicides vary in antifungal spectrum, and certain members of the group exhibit surprising activities: Prochloraz and imazalil have strong activity against *Alternaria;* etaconazole/propiconazole show unusual activity against *Geotrichum*. In addition to the EBIs, other fungicides have unique activity against certain postharvest pathogens difficult to control. Iprodione has controlled *Alternaria* rot in situations where strong systemic action is not essential. This fungicide also controls postharvest diseases caused by *Penicillium, Botrytis, Sclerotinia,* and *Monilinia*. Guazatine is uniquely effective against *Geotrichum* sour rot as well as benzimidazole-resistant *Penicillium* spp., and this fungicide is being developed commercially as a postharvest treatment for citrus fruits. Finally, metalaxyl and fosetyl aluminum have been successful in eradicating *Phytophthora* (incubating infections) on citrus fruits.

Fungicides and application techniques are available today to provide practical control of the major postharvest diseases of subtropical and tropical fruit crops. This statement is based, to a certain degree, upon experimental successes rather than practical accomplishments. While virtually all of the important diseases have been controlled under simulated-commercial conditions, the effective chemicals and techniques may not be permitted in all countries, and may not be available, affordable, or practical under all circumstances. Nonetheless, research over the past two decades has revealed the potential of postharvest chemical treatments to control, and in many cases eradicate, incipient infections of diverse pathogens on harvested fruit crops. While the appropriate strategies for postharvest disease control are generally recognized, it is probable that more effective postharvest fungicides and application techniques remain to be discovered. For example, benomyl is effective against anthracnose of tropical fruits when the solution is heated to around 50°C, depending upon the concentration, whereas prochloraz and etaconazole are effective at ambient temperature. The probable effect of increased temperature is to increase the solubility and diffusion of benomyl through the hydrophobic surface layers of the fruit in order to reach the latent infections. Therefore, it seems reasonable that the effectiveness of benomyl and other fungicides as postharvest treatments could be improved significantly by improved formulation. Additional impetus for continuing research on the control of postharvest diseases of subtropical and tropical fruit crops is provided by the fact that the number of effective fungicides for certain postharvest applications is limited, especially since the development of resistance to one EBI fungicide will probably be accompanied by cross-resistance to all other fungicides in this class.

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